Moisture Conservation and Use at Swift Current -
A Comparison to Previous Findings

C.A. Campbell and R.P. Zentner

Abstract

The results of an ongoing 18 year crop rotation study at Swift Current were compared to those reported 30 - 40 years earlier. The two periods showed no difference in over winter moisture conserved for stubble or fallow-systems. Moisture conserved in the 9 months (fall and winter) period on stubble was 34% of the precipitation received in this period while 18% of precipitation received in the 21 month fallow period was conserved. These compare with earlier reports for these two periods which were 33% and 21% respectively.

The 18 year average moisture use efficiency for the current study averaged between 6.9 $kg.ha^{-1}.mm^{-1}$ moisture used (mu) for fallow-seeded wheat and a low of 5.1 $kg.ha^{-1}.mm^{-1}$ for continuous wheat that received P but no N fertilizer annually. Here mu was defined as spring soil moisture - Harvest soil moisture plus precipitation received from May 1 to August 31. These efficiencies for the more recent period were much higher than those reported by Staple and Lehane for the period 1939 - 1950 where fallow wheat would produce 4.5 $kg.ha^{-1}.mm^{-1}$ and stubble - wheat produce 3.7 $kg.ha^{-1}.mm$.

The relationship between yield and mu for stubble crops was best described by a quadratic model while a linear model best fit the fallow crop data. The equation for the fallow system for the recent study was $y = -397 + 8.69$ mu ($r=0.77$**) while Staple and Lehane reported $y = -1298 + 9.32$ mu ($r=0.83$**). These equations suggest that the rate of increase per mm of mu are approximately the same for the two periods studied but that in more recent times wheat is making more efficient use of smaller amounts of moisture. For example, while Staple and Lehane predict that 139 mm of moisture was required to produce 1 $kg.ha^{-1}$ of grain, we find that only 46 mm is now required for fallow-seeded wheat to produce 1 $kg.ha^{-1}$.

MOISTURE CONSERVATION AND USE AT SWIFT CURRENT - A COMPARISON TO PREVIOUS FINDINGS

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In the 1940's to 50's Staple and Lehane carried out a series of studies in the Brown soil zone in the area around Swift Current in which they thoroughly and effectively characterized soil moisture behaviour and wheat response to moisture (Staple and Lehane 1952; Staple et al. 1960; Staple and Lehane 1954). Cereal management methods have improved since then in terms of efficiency of herbicide use for weed control, fertilizer use, and timeliness of operations.

A long-term crop rotation study at Swift Current (Campbell et al. 1983 a b; Zentner et al. 1984) presented an opportunity to reassess and compare soil moisture conservation, moisture use efficiency (MUE) and the quantitative relationship between yield and moisture used, to the results previously obtained by Staple, Lehane and others.

MATERIALS AND METHODS

The Swift Current crop rotation experiment was initiated in 1967 on a Swinton loam (Ayres et al. 1985), an Orthic Brown Chernozem (Canada Soil Survey Committee, Subcommittee on Soil Classification 1978). Organic nitrogen (N) concentration in the upper 15 cm is about 0.18% and the pH 6.0-6.5 (in water paste). Twelve crop rotations were established on 81 plots in a 3 replicate randomized design, but only 7 spring wheat producing rotations are discussed in this paper (Table 1). All stages of each rotation were present each year. Each rotation was cycled on its assigned plot. For ease of reference, rotation-year (Rot-yr) treatments were designated by rotation number followed by year number (e.g., rotation 1, year 1 = Rot-yr 1-1).

Table 1. Crop rotations and treatments

Rot. No.	Rotations	Comments
1	(Fallow)*-wheat-(wheat)	P applied, no N applied
2	Fallow-wheat-(wheat)	N and P applied
3	Fallow-flax-(wheat)	N and P applied
5	Fallow-wheat-wheat	N applied, no P applied
8	(Continuous wheat)	N and P applied
11	Fallow-(wheat)	N and P applied
12	(Continuous wheat)	P applied, no N applied

*Plots indicated by ( ) were sampled at eight regular intervals for nutrients, and soil moisture; when cropped they were also sampled for plant dry weight.

A description of the field operations is published (Campbell et al. 1983 a,b; Zentner et al. 1984), therefore only a brief summary of this aspect is provided here. Full-sized farm machinery was used for all field operations. Summerfallow tillage was performed two to five times with a heavy-duty cultivator and/or rod weeder. Late fall application of 2,4-D ester was customary and other herbicides were applied to cropped areas as required. Fertilizer N and P were applied in accordance with rotation specifications decided at outset of the study and based on the general recommendations of the Saskatchewan Soil Testing Laboratory. Crops grown on fallow received, on average, 5 $kg.ha^{-1}$ N annually; those crops grown on stubble received 30 kg.ha^{-1} N when the rotation included fallow and those in the continuous-type rotations generally received N at 35-45 kg.ha^{-1}. All crops supplemented with P received P_2O_5 at 22 kg.ha^{-1}. The N was broadcast in the spring as 34-0-0 and soil incorporated while the P applied as 11-48-0 was seed-placed. Plant and soil sampling details are listed in the references already cited.

Data Analysis

Moisture conserved in the soil was calculated for four arbitrarily chosen intervals of the fallow period. These included: (1) harvest of the crop year to freeze-up; (2) freeze-up to early spring; (3) spring to freeze-up of the fallow year; and (4) freeze-up to just before spring seeding. The 18 year average dates for these periods were: (1) August 28 - October 15; October 16 - May 4; (3) May 5 - October 15; and (4) October 16 - May 5. For stubble cropping, only the first two time-intervals applied.

The amount of moisture used per unit mass of grain produced (MUE) was calculated as grain yield (kg.ha^{-1}) divided by the sum of growing season precipitation (GSP) plus the difference in soil moisture (0- to 120-cm depth) between early spring (Sp) and harvest (Ha). In this paper, unless specified otherwise, GSP refers to the period from May 1 to August 31 as used by Staple and Lehane (1952). A second parameter designated efficiency of use of precipitation was calculated as grain yield divided by the amount of precipitation received during the period from harvest of the previous crop to harvest of the crop in question. In the latter, efficiency was based on the entire rotation as opposed to per rotation-year.

Volumetric moisture content was calculated as % moisture by wt x bulk density x depth. In this soil, moisture held at -1.5 MPa in 0- to 30-, 30-

to 60-, 60- to 90- and 90- to 120-cm deths were 39.1, 40.0, 42.3 and 46.6 mm, respectively, for a total of 168 mm/120 cm of soil. The lower limits of available moisture (Ritchie 1981) for these same depths were 33.6, 33.1, 38.0 and 43.2 mm, respectively, for a total of 147.9 mm. Regression analysis was used to relate grain yield to moisture used during the growing season.

The relative contribution to yield variability caused by precipitation received during the various growth periods was determined by multiple linear regression of yield on precipitation during the periods divided by length of the periods in days. The standard partial regression coefficients were calculated from the regression; separate relationships were calculated for stubble and fallow-wheat systems.

RESULTS AND DISCUSSION

Precipitation and Evaporation

Over the 18 year period, GSP averaged 33 mm/yr less than the long-term average at Swift Current (Table 2). It was greater than the long-term average in 9 of 18 years and was very low in 1967 and 1973. Distribution of precipitation was often less than ideal such as when precipitation was concentrated in short periods early (1970), or late (1968, 1974) in the growing season. During the 18 years, precipitation, during the period September 1 to April 30 averaged 145 mm, i.e., about average for this area. This precipitation was generally much higher in the first 9 years of the study than in the last 9 years (Table 2).

Table 2. Precipitation and class A pan evaporation at experimental site near Swift Current

Year	Precipitation (mm) May	June	July	Aug.	Growing Season Precip. (mm)	Growing Season Pan Evap. (mm)	[‡]Precip. during previous fall and winter (mm)
1967	36	16	5	32	89	1087	185
1968	20	23	20	55	118	992	147
1969	23	29	80	3	135	1033	200
1970	23	186	27	9	245	958	170
1971	11	68	42	4	125	1104	150
1972	54	56	26	11	147	993	105
1973	10	23	18	30	81	1138	180
1974	85	21	44	107	257	911	202
1975	38	61	38	71	208	855	138
1976	23	122	45	39	229	1069	177
1977	102	24	72	26	224	878	66
1978	45	63	11	17	136	943	145
1979	52	51	34	29	166	948	164
1980	13	70	76	32	191	947	96
1981	39	98	59	16	212	952	143
1982	82	43	119	41	285	758	124
1983	62	29	96	18	205	1018	143
1984	19	67	15	18	119	1180	83
18-yr mean	41	58	46	31	176	987	145
[+]Long-term mean	43	72	52	42	209	988	151

[+] Period of 100 yr for precipitation and 25 yr for evaporation.

[‡] For example, for 1967 the period represented is Sept. 1, 1966 to April 30, 1967.

Precipitation Received and Moisture Conserved

The average amount of precipitation received during the first fall and winter period was 174 mm; Staple and Lehane received 165 mm in this period (Table 3). Of the 174 mm, three-fourths came during winter. During the 21-month fallow period, we received 545 mm of precipitation while Staple and Lehane received 475 mm. Of the 545 mm, 43% came during the spring to the end of the second fall. As shown in Table 3 and found by Staple and Lehane (1952) moisture conservation did not reflect these proportions.

Table 3. Precipitation received during several periods and water conserved on stubble and fallow rotations (18 year average).

Period+	Precip. Received (mm)	Moisture Conserved in soil (mm)		% of Period Precip. Conserved in Soil	
		(N & P Fert.)	(P only)	(N & P Fert.)	(P only)
	Stubble rot-yr:	2-3 & 8-1	12-1	2-3 & 8-1	12-1
Fall	42 (56)	9	9	21	20
Winter	132 (109)	48	36	36	27
Total (9 months)	174 (165)	57 (56)	45	33 (34)	26
	Fallow rot-yr:	1-1+2-1+11-1		1-1+2-1+11-1	
First Fall	44 (56)	11		26	
First Winter	135 (109)	48		36	
Spring to end Fall	232 (198)	28		12	
Second Winter	134 (112)	9		7	
Total (21 months)	545 (475)	96 (101)		18 (21)	

+Fall = Aug. 28 - Oct. 15; Winter = Oct. 16 - May 4; Spring to end second fall = May 5 - Oct. 15; (18 year average periods).

( ) Values in brackets taken from Staple and Lehane (1952)

In our study about 20-26% of the first fall's precipitation was stored in the soil. Except for Rot-yr 12-1, about 36% of the precipitation received in the first winter was stored in the soil; the continuous wheat rotation that received no N stored only 27%. The latter was likely due to lower production and consequently less crop residues (Table 4) available to trap snow in Rot-yr 12-1.

On fallow areas, only 12% of the 232 mm of summer and second fall's precipitation was stored in the soil and only 7% of the second winter's 134 mm was stored (Table 3). Of the precipitation received between harvest and spring seeding, the proportion stored in stubble land was 33% for the adequately fertilized treatments, the same as that reported by Staple and Lehane (1952), and 26% for the poorly fertilized continuous wheat treatment (rot-yr 12-1). Only 17.7% of the precipitation received during the 21month fallow period was stored in soil. Although this seems less than the 21% reported by Staple and Lehane (1952), in both of these studies there was considerable variation in moisture stored in the 21-month period, thus our results can be regarded as no different from those of the earlier study.

The amount of moisture conserved in the soil during the first fall (8 to 11 mm) was not affected ($P < 0.05$) by rotation or fertilizer. Moisture stored in the soil during the first winter was 3 to 5 times that stored in the first fall. This amount was not affected ($P < 0.01$) by rotation; however, the poorly fertilized continuous wheat (Rot-yr 12-1) conserved significantly less moisture (12 mm less) than the well-fertilized stubble-seeded and fallow-seeded rotations.

Moisture Use by Wheat

Moisture used from soil. Moisture used from the soil by the crop (SpSM - HaSM) varied annually and was negatively related to GSP ($r = -0.33$ to

Table 4. 18-yr Average and variability in wheat yields, +available spring soil moisture, **growing season precipitation and **growing season pan evaporation.

Rot-yr	Rotation	Fert.‡ N	Fert.‡ P	+Available Spring Soil Moisture ($mm.120\ cm^{-1}$) Avg	Max	Min	Cv (%)	Grain Yield ($kg.ha^{-1}$) Avg	Max	Min	Cv (%)	Straw Yield $kg.ha^{-1}$ Avg.	Straw: Grain Ratio
11-2	F - W*	√	√	103	146	46	31	1898	3207	1075	30	3356	1.77
2-2	F - W - W*	√	√	106	159	41	30	1912	3126	1008	29	3314[x]	1.75
1-2	F*- W - W*	0	√	101	163	30	38	1872	3229	974	31	3248[x]	1.74
5-2	F - W - W	√	0	97	146	38	30	1715	2901	872	30	2989[x]	1.74
3-3	F-Flx-W*	√	√	62	148	0	98	1376	2392	67	44	2279	1.66
2-3	F - W - W*	√	√	64	152	0	89	1403	2732	67	45	2452	1.75
1-3	F - W - W*	0	√	65	153	8	80	1307	2511	134	43	2153	1.65
5-3	F - W - W	√	0	63	155	8	88	1263	2482	134	40	2244[x]	1.78
8-1	Contin W*	√	√	62	158	0	95	1354	2454	201	37	2289	1.69
12-1	Contin W*	0	√	55	146	4	99	1162	2050	269	39	1802	1.55

Meteorological Parameters	Avg (mm)	Max (mm)	Min (mm)	Cv (%)	Long-term Avg (mm)
**Growing Season Precip. (GSP)	145	244	50	39	167 (99 yr)
**Growing Season Pan Evap.(GSE)	723	854	529	11	727 (25 yr)

+ Water held at the lower limit of availability (Ritchie 1981) (i.e., 148 mm/120 cm depth in soil).
* These special plots were sampled for nutrients and soil moisture at eight regular intervals from about mid May to mid October. Data in the table refers to the underlined rot-yr.
‡ denotes fertilizer applied; 0 denotes no fertilizer applied.
** Growing season here was May 1 to July 31. Similar values for May 1 to Aug. 31 for precipitation were 176, 285, and 81 mm and for Pan evaporation 987, 1180 and 758 mm for the 18 year average, maximum, and minimum, respectively
x Estimated from straw yield = 163 + 1.65 grain yield (r=0.75**)

-0.60) indicating that plants make greater use of stored soil moisture in dry years than in wet years. The fallow-seeded wheat rotations that received P annually used an average 102 mm of moisture from the soil per se i.e., slightly less than the 109 mm reported used in earlier studies (Staple and Lehane 1952). Fallow-seeded wheat receiving no P (Rot-yr 5-2) used 93 mm. The well-fertilized stubble-seeded Rot-yr used, on average, 61 mm compared to 50 mm used by continuous wheat that received no N (Rot-yr 12-1). The difference in moisture used from fallowed land compared to stubble reflects the relative amount of stored soil moisture that was present initially in these two systems.

Moisutre use efficiency. There were significant ($P < 0.05$) differences between the Rot-yr groupings shown in Figure 1. The 18 year mean MUE was as high as 6.9 $kg.ha^{-1}.mm^{-1}$ for fallow-seeded wheat receiving P annually and as low as 5.1 $kg/ha^{-1}.mm^{-1}$ for continuous wheat receiving P but no N. Well-fertilized stubble-seeded wheat had an average MUE of 5.7 $kg.ha^{-1}.mm^{-1}$. These values are much greater than those reported in studies carried out in this area between 1920 - 1960 where MUE for fallow-seeded wheat was reported as 4.5 $kg.ha^{-1}.mm^{-1}$ and for stubble-seeded wheat 3.7 $kg.ha^{-1}.mm^{-1}$ (Staple and Lehane 1952, 1954). The greater efficiency obtained in our study reflects improvement in crop management and crop varieties. Values similar to ours were obtained in the earlier period when the study was done in outdoor tanks (de Jong and Cameron 1980), thus reflecting benefits of optimum management. In our study, less than adequate fertilization reduced MUE significantly ($P < 0.01$). Similar findings are frequently reported in the literature (Warder et al. 1963; de Jong and Rennie 1969; Bauer 1972).

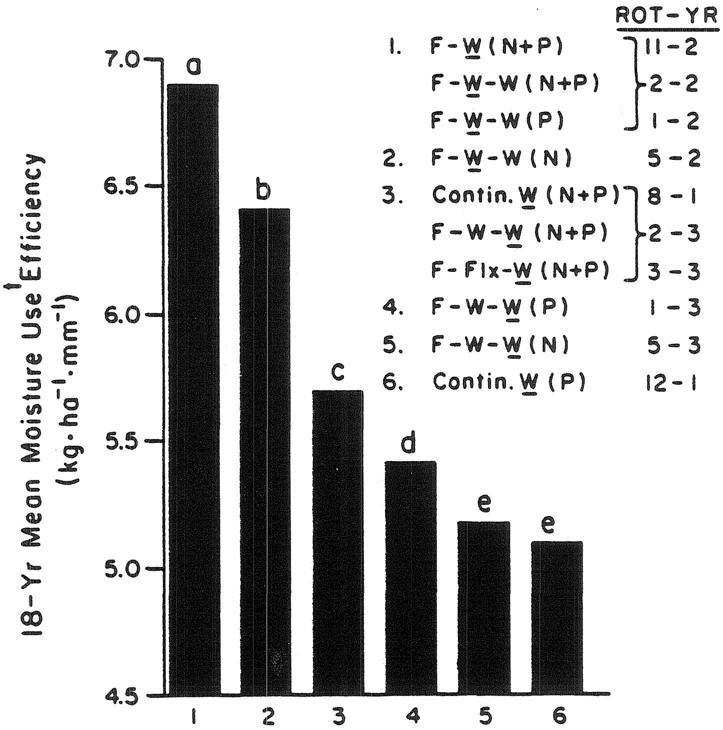

Figure 1. Effect of Rot-yr and fertilizer on 18-yr mean moisture use efficiency (MUE). [Values for treatments followed by the same letter were not significantly different ($P < 0.05$)].

Efficiency of use of precipitation. The latter method of calculating MUE does not charge the inefficiency of moisture conservation by the summerfallow process to that cropping system. To address this shortcoming another efficiency parameter designated as efficiency of use of precipitation was calculated for each rotation (not Rot-yr). Here efficiency was expressed as a function of precipitation received from harvest to harvest (Figure 2). Efficiency in this case increased with cropping frequency within a rotation so that the 2-year fallow-wheat rotation (Rot 11) now ranked last instead of first. The efficiencies ranged between 3.75 $kg.ha^{-1}.mm^{-1}$ for well-fertilized continuous wheat (Rot

†(Calculation based on precipitation received from harvest to harvest for the entire rotation)

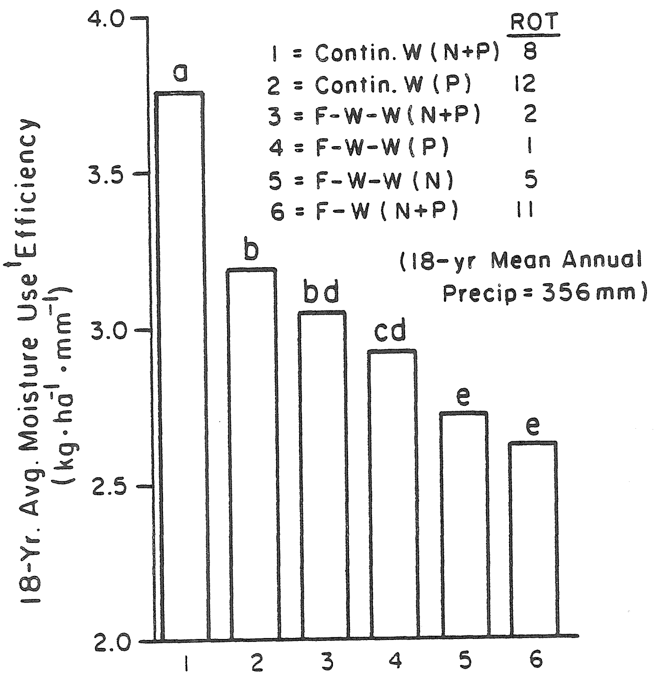

Figure 2. Effect of crop rotation and fertilizer on efficiency of use of precipitation. [Values for treatments followed by the same letter were not significantly different ($P < 0.05$)].

8) and 2.60 $kg.ha^{-1}.mm^{-1}$ for fallow-wheat (Rot 11). In contrast, de Jong and Cameron (1980) calculated values for Saskatchewan for the periods between 1940 and 1970 as being between 1.8 and 2.3 $kg.ha^{-1}.mm^{-1}$. The latter data were calculated for cropping systems containing 49-62% fallow cropping and the annual precipitation in the three 10 year periods they examined were between 370 and 400 mm annually, i.e., slightly higher than our 18 year mean of 356 mm. We can only reasonably compare values for our Rot-11 to their values and, although we recognize differences in method of calculation and precipitation, our efficiencies do appear to be higher than for the earlier period.

Quantitative Relation Between Yield and MU

When grain yield was related to moisture used by the crop by regression analysis, it was found that using GSP as that for May 1 to July 31 gave more precise relationships than the use of May 1 to August 31, therefore, except for a comparison to Staple and Lehane's data, GSP in the remainder of this paper refers to the period May 1 to July 31.

When the 18 year data were used to relate yield to mu, the stubble treatment was best fitted by a quadratic model (Figure 3, top and Table 5). When the relationships for four stubble treatments were differentiated and examined in more detail, they showed that yield approached 1 $kg.ha^{-1}$ when MU was 50 - 60 mm for the less well fertilized systems (Rot-yr 5-3 and 12-1) and about 80 mm for the well fertilized systems (Rot-yr 2-3 and 8-1). This supports the observation that yield response to fertilizer is often negative in dry years. Well fertilized systems deplete soil moisture more rapidly and plants wilt during prolonged droughts while poorly fertilized crops use moisture more slowly and often survive longer in a drought (Bond et al. 1971; Campbell et al. 1977). Yield increase per mm increase in moisture used was inversely related to the quantity of moisture used; it reached zero at 280 mm of MU, limited most likely by fertility. Fertilization increased MUE.

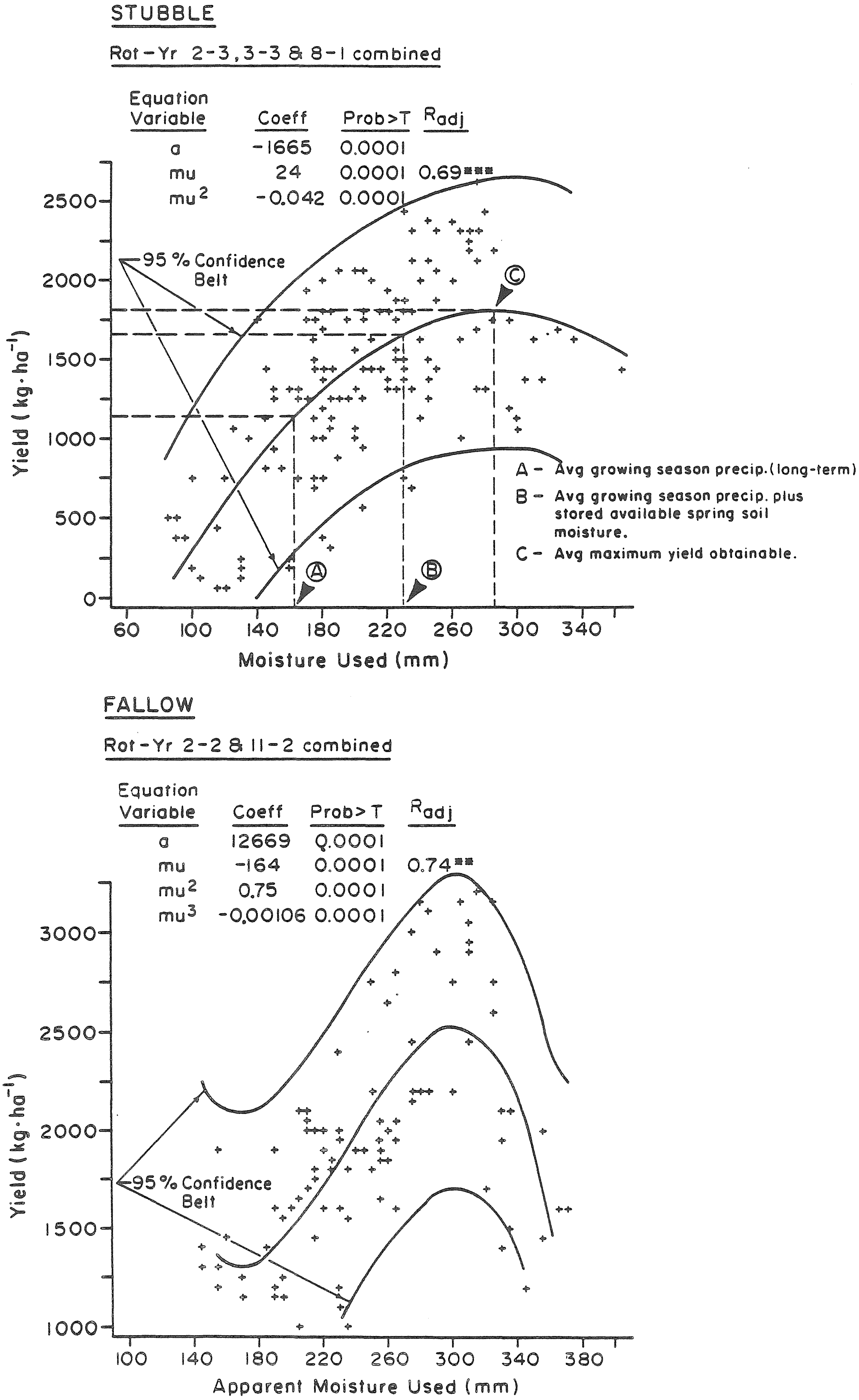

Figure 3. Relationship between yield and moisture used (MU) for well-fertilized rotations. Top: Stubble-seeded; Bottom: Fallow-seeded wheat; [MU = GSP plus (spring-harvest soil moisture in 0-120 cm depth)]. GSP = May 1 - July 31. (18 year data)

Table 5. Relationship between spring wheat yield and moisture use (MU) for wheat grown on stubble. (18 year data)

Parameters Rot-yr:	F - W - $\overline{W}$ (N + P) (2-$\overline{3}$)	F - W - $\overline{W}$ (+ N) (5-$\overline{3}$)	Contin. $\overline{W}$ (N + P) ($\overline{8}$-1)	Contin $\overline{W}$ (+ P) (12$\overline{-}$1)
†Equation	$y=-1768+25.2mu-0.045mu^2$	$y=-830+14.7mu-0.021mu^2$	$y=-1475+22.2mu-0.038mu^2$	$y=-832+16.8mu-0.031mu^2$
R_{adj}	0.64***	0.65***	0.65***	0.52***
mu when yield = 0	82	50	76	59
‡Moisture used (mm)	-------- Yield increase per mm moisture used ------------ ($kg.ha^{-1}.mm^{-1}$)			
100	16	11	15	11
200	7	6	7	4
280	0	3	1	- 1

† The lowest levels of moisture used in stubble-seeded systems was about 80 mm.

‡ Y = yield ($kg.ha^{-1}$); mu = moisture used (mm) [(i.e., SpSM - HaSM) + GSP] where GSP is for May 1 to July 31.

When the 18 year data were used to relate yield of wheat grown on fallow to MU, a cubic function fitted the data most precisely (Figure 3, Bottom). However, this model seems unrealistic since as we all know much higher yeilds are usually obtained at higher MU on irrigation. In Figure 3 (bottom) the turn down part of the curve at high moisture use was due to two years (1970 and 1983) in which poor timing of precipitation (Table 2) resulted in leaching beyond the root zone (Campbell et al. 1983b). If allowance were made for this unused water, the points for 1970 and 1983 on Figure 3, Bottom would shift to the left and the response might actually be linear. Since we did not have sufficient data to estimate the amount of leaching that took place in 1970 and 1983, we omitted these data from the quantitative analysis.

Regression using the 16 year data for fallow seeded rotations showed that a linear relationship best fit the data (Figure 4). These results were calculated with GSP for May 1 to August 31 and compared to Staple and Lehane (1954) data. While Staple and Lehane (1954) obtained the relation y = -1298 + 9.32 MU (r = 0.83***) we obtained y = -397 + 8.69 MU (r = 0.77***). Thus, the rates of increase in yield per unit of moisture used were not too different for the two studies. However, while Staple and Lehane showed a requirement of 139 mm of MU before any yield is achieved our data suggest 46 mm is required. Consequently, for a given MU we have achieved about 700 $kg.ha^{-1}$ greater yield compared to the earlier data. De Jong and Halstead (1987) obtained very similar data to ours based on the Sask. Inst. of Pedology Farm Lab study results. The reason for the vast improvement in MUE favoring our study does not appear to be due to the difference in MU from the soil (105 mm vs 98 mm) or GSP (164 vs 170 mm) where the first value of each set is from Staple and Lehane (1954) and the second represents the 16 year mean of our study. As stated earlier, crop management, fertilization and superior cultivar are probably responsible for this dramatic improvement in MUE in recent years. We have already shown that moisture conservation over winter was not responsible for the improvement. The earlier study was carried out during the war years and weed control was not always the best due to labour shortage. Further, it does not appear that any fertilizers were used in the earlier study; our results show the benefits of applying P fertilizers to fallow-seeded crops.

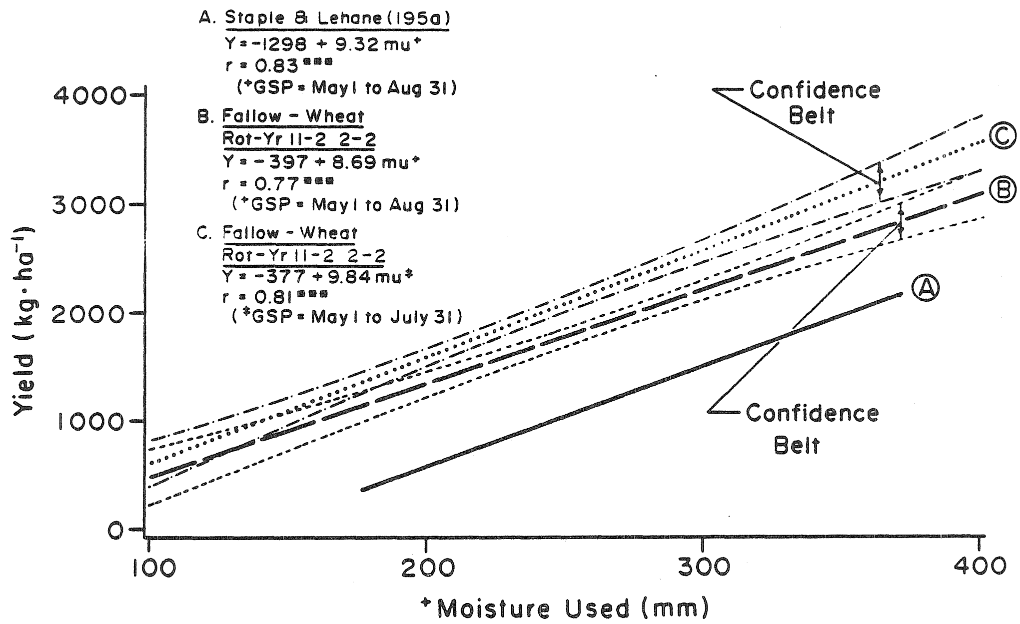

Figure 4. Relationship between grain yield and moisture use for wheat grown on fallow - our results compared to Staple and Lehane (1954). (MU = SpSM - HaSM & GSP)

Relative Effect of Distribution of GSP on Yield

The distribution of precipitation has a significant influence on grain yield. The relative effect of precipitation received during the various growth periods on yield is shown in Figure 5. For both fallow- and stubble-seeded systems, precipitation received during grain development (five leaf to soft dough) was very important as also shown by Bauer (1972), but for stubble-seeded crops on dryland, precipitation at seeding was just as important since it is required to ensure proper plant establishment. The latter has not been fully emphasized in the past. Because of the higher stored soil moisture in fallow, the influence of GSP on yield only becomes critical after the five leaf stage when stored water would normally become depleted if early GSP was low.

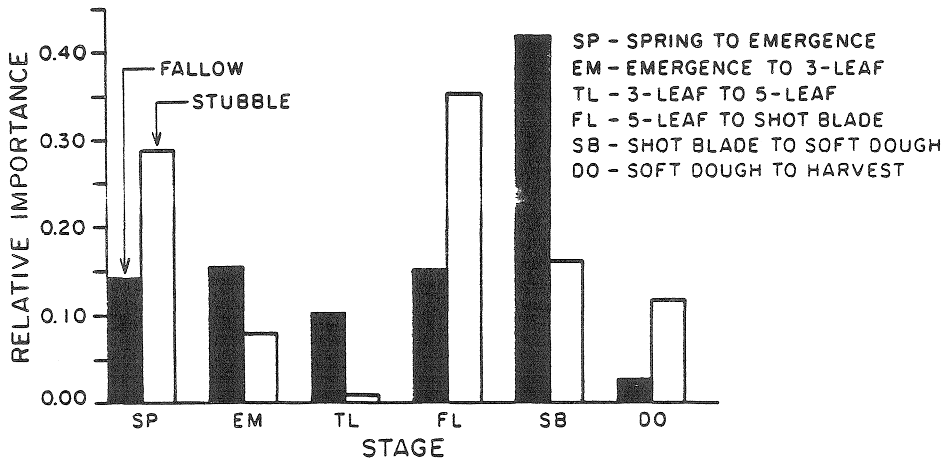

Figure 5. Growth periods when GSP is most critical to yields.

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